6.5.2.1. Smooth stray-load loss data by using a linear regression analysis.

$$W_{LLave} = A(I_{2ave})^2 + B \qquad \text{(Eq 25)}$$

where

W_{LLave} = average value of stray-load loss as plotted versus approximate rotor current squared
A = slope
B = intercept with the zero current line
I_{2ave} = average value of rotor current

The value of rotor current, I_2, for each direction of power flow (motoring and generating) is taken as

$$I_2 = \sqrt{(I^2 - I_o^2)} \qquad \text{(Eq 26)}$$

where

I = observed value of stator line current (motoring or generating) for which stray-load loss is to be determined
I_o = value of no-load current

The corrected value of stray-load loss is

$$W_{LLc} = A(I_2)^2 \qquad \text{(Eq 27)}$$

6.5.3 Motor/Generator Performance. Calculate motor or generator performance using 10.3, which includes temperature correction. Determine W_{LLc} based on the slope, A, and the value of rotor current, I_2, appropriate to the load point for which stray-load loss is to be determined.

The value of rotor current for each load point is calculated as

$$I_2 = \sqrt{(I^2 - I_o^2)} \qquad \text{(Eq 28)}$$

where

I = operating value of stator line current for which stray-load loss is to be determined
I_o = value of no-load current

6.6 Test Method E or E1 — Electrical Power Measurement With Loss Segregation. The input should be measured as outlined below. The output should be determined by subtracting the total losses from the input. The total losses equal the sum of the stator and rotor I^2R losses corrected to the specified temperature for resistance correction, core loss, friction and windage loss, and stray-load loss.

6.6.1 Test Procedure

6.6.1.1. No Load Test. See 5.3.

6.6.1.2.Test Under Load. To obtain the required data, it is necessary to couple, belt, or gear the machine to a variable load. The same arrangement that is used for the temperature test may be employed. For each of six approximately equally-spaced points, the read-

ings of electrical power, current, voltage, slip, ambient temperature, and stator winding resistance or temperature are to be recorded.[11] The stator winding resistance for each load point can be estimated by comparing the temperature rise measured by an embedded temperature detector, a temperature sensor located on the stator coil end, or the air outlet temperature rise, with corresponding temperature rise measurements obtained as steady state values during a temperature test.

6.6.1.3. Stray-Load Loss Test

6.6.1.3.1 Test Method E. See 5.4.2 or 5.4.3.

6.6.1.3.2 Test Method E1. See 5.4.4.

6.6.2 Stator I^2R Losses. See 5.1.

6.6.3 Rotor I^2R Losses. See 5.2.

6.6.4 Core Loss. See 5.3.5.

6.6.5 Friction and Windage. See 5.3.4.

6.6.6 Stray-Load Loss (Direct Measurement)

6.6.6.1 Rotor Current I_2. The value of rotor current shall be calculated as

$$I_2 = \sqrt{(I^2 - I_0^2)} \qquad \text{(Eq 29)}$$

where

I = operating value of stator line current for which stray-load loss is to be determined
I_0 = value of no-load current

The value of stray-load loss, W'_{LL}, reported in 10.4 shall correspond to a value of rotor current, I'_2, as calculated from Eq 29 for a value of I corresponding to the rated value of stator line current.

6.6.7 Motor/Generator Performance. Calculate motor or generator performance using 10.4, which includes temperature correction.

6.7 Test Method F or F1 — Equivalent Circuit. When tests under load are not made, operating characteristics (efficiency, power factor, torque, etc.) are calculated based upon the equivalent circuit shown in Fig 2. The machine parameters in the equivalent circuit are derived from test data recorded during a no-load test and an impedance test. Accurate prediction of machine characteristics in the normal operating range will depend primarily upon the closeness by which r_2 represents the actual rotor resistance to currents of low frequency and, secondarily, upon the closeness by which x_2 represents the actual rotor leakage reactance to currents of low frequency. Therefore, the most careful procedure during testing to determine the rotor characteristics at low frequency is imperative.

[11] See footnote 10.

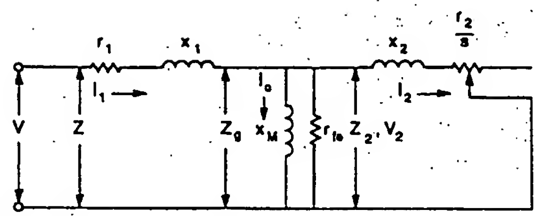

Fig 2
Equivalent Circuit

6.7.1 Test Procedure

6.7.1.1 No-Load Test. See 5.3.

6.7.1.2 Impedance Test. Readings of voltage, current, electrical input power, and stator resistance or stator winding temperature are to be taken at one or more frequencies, voltages, and/or loads. This data is referred to as the impedance data. If the machine being tested has a wound rotor, the rotor is to be short circuited for the test.

The reactance shall be measured at rated load current. It is important that the value of reactance used in the equivalent circuit calculation is at the correct value of saturation and deep bar effect; otherwise, the calculated power factor will be found to be higher than the true value.

The impedance data shall be determined from one of the following methods:[12]

(1) Three-phase locked-rotor impedance test at maximum of 25% of rated frequency and at rated current.[13] See 6.7.1.2.1 for details.
(2) Three-phase locked-rotor impedance test at rated frequency, at approximately 50% of rated frequency, and at a maximum of 25% of rated frequency, all at rated current. Curves shall be developed from these three test points and used to determine the values of total reactance and rotor resistance at the required reduced frequency.[14] See 6.7.1.2.1 for details.
(3) An impedance test above the speed of the breakdown point at a slip speed approximating the desired reduced rotor frequency. In this method, the motor is run uncoupled or coupled to a reduced load, and the voltage is reduced to give approximately full load slip point. The slip must be measured carefully. See 6.7.1.2.2 for details.
(4) When none of the above methods is practical, the following test may be utilized: a three-phase, locked rotor impedance test at reduced voltage at rated frequency resulting in approximately rated current and a test under load. See 6.7.1.2.3 for details.

[12] The impedance thus determined is at the temperature of the motor at the time of the test.

[13] The total reactance of the machine for use in the performance calculation by Section 10, Method F, is computed from the reactance determined at reduced frequency by multiplying the low-frequency value by the ratio of rated frequency to the low frequency. In general, the reactance so determined will be larger than when directly measured at normal frequency, the difference being small for single squirrel-cage rotors and relatively large for double squirrel-cage or deep bar rotors.

[14] See footnote 13.

6.7.1.2.1 Locked-Rotor Tests. The rotor of a squirrel-cage motor is a symmetrical bar winding; therefore, the impedance of the motor is practically the same for any position of the rotor relative to the stator.

The impedance of a wound-rotor motor varies with the position of the rotor relative to the stator. It is therefore necessary when performing a locked-rotor impedance test to determine the rotor position that results in an average value of impedance. Before taking readings on wound-rotor machines, the rotor shall be short circuited. The angular distance through which it is necessary to observe the current variation shall be determined by allowing the rotor to revolve slowly and observing the stator current, noting the distance the rotor must move for the stator current to complete a cycle. For machines having an integral number of slots per pole per phase in both rotor and stator, this distance will be equal to two-thirds of a pole pitch for three-phase machines. For machines having fractional slot windings, the angular distance may be as much as a full pole pitch.

The rotor shall be blocked so that it cannot move; and the impressed voltage shall be increased gradually until a current of approximately rated value is obtained. Voltage and current on all phases shall be read and recorded, and the voltage in the different phases shall be balanced. Holding the same voltage, the rotor shall be turned slowly and the minimum and maximum values of current during a complete cycle recorded. The rotor shall then be blocked for the impedance test on the position that gives a current equal to the average of the minimum and maximum values previously recorded.

(1) Take simultaneous readings of voltage and current in all phases and of power input at several levels of voltage in order to establish the value with special care in the neighborhood of full-load current. The stator winding temperature or stator winding resistance shall also be recorded. Care shall be taken not to overheat the windings. Taking the highest readings first and the lower readings in succession will help to equalize the temperature.

    Plot curves using volts as abscissas and amperes and the algebraic sum of the watt-meter readings as ordinates. The curve of amperes vs. volts is usually a straight line, curving slightly upward at the higher values. On closed slot rotors, however, there is also a distinct curve upward at low voltage. Derive the value of voltage and power input to determine the total reactance and rotor resistance at the required level of current from these curves.

(2) Determine the rotor resistance, r_2, and the total leakage reactance, $x_1 + x_2$, from these data using the equations of 10.5. When using Method 2, curves of the values of rotor resistance and total leakage reactance vs. frequency should be used to determine the value at the desired operating frequency.

6.7.1.2.2 Impedance From Reduced-Voltage, Reduced-Load Running Test. The rotor resistance, r_2, and the leakage reactance, x_2, at reduced frequency may be obtained from readings (volts, watts, amperes, slip, stator winding temperature, or stator winding resistance) at a slip speed approximating the desired reduced rotor frequency. In this method, the machine is run uncoupled or coupled to a reduced load and at a voltage that gives the desired slip speed. The slip must be measured very carefully. The following procedure is used.

When data from the no-load saturation test is available (see 5.3), calculate the total reactance per phase for each test point and draw a curve of total reactance per phase vs. no-load volts per phase (see example in Fig 3). Use the highest point on this curve as the total no-load reactance per phase, $X_1 + X_m$, in calculations of the low-voltage slip test.

When a complete no-load test has not been performed, the total reactance per phase at rated voltage and no load can be used as the total no-load reactance per phase, $X_1 + X_m$, in calculations of the low-voltage slip test.

From the low-voltage slip test data, calculate the impedance per phase, Z, the resistance per phase, R, and the reactance per phase, X. Also calculate $\cos\theta_1 = R/Z$, and $\sin\theta_1 = X/Z$.

If the design details are available, use the calculated ratio X_1/X_2. Otherwise use the ratios given on Form F-1 (see 10.5).

$$X_1 = X \cdot \frac{\left(\frac{X_1}{X_2}\right)}{\left(\frac{1+X_1}{X_2}\right)} \quad \text{(Eq 30)}$$

Using the value of total no-load reactance, $X_1 + X_m$, determined above, the value of the magnetizing reactance, X_m, can be approximated as

$$X_m = (X_1 + X_m) - X_1 \quad \text{(Eq 31)}$$

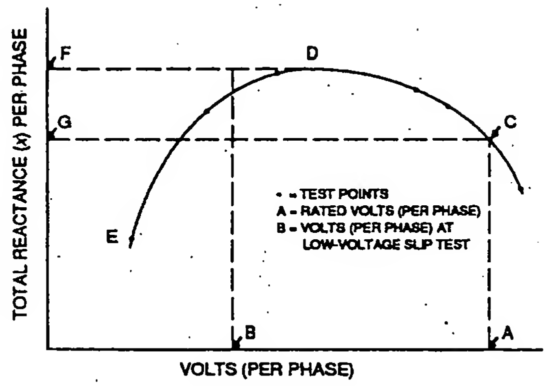

Fig 3
Total Resistance From No-Load Test

A = rated volts
B = volts at low-voltage slip test
CDE = curve of total reactance from no-load test
F = reactance corresponding to the highest point, D, of the test curve CDE. This value is used as the total reactance, $X_1 + X_m$, in calculations of the low-voltage slip test
G = total reactance, $X_1 + X_m$, to be used in determining X_m for use in the equivalent circuit calculations after X_1, X_2, and R_2 are determined from the calculations of the low-voltage slip test

From the data obtained from the low voltage slip test, calculate

$$V_2 = \left\{\left[V_1 - I_1(X_1 \sin\theta_1 \pm R_1 \cos\theta_1)\right]^2 + \left[I_1(X_1 \cos\theta_1 \mp R_1 \sin\theta_1)\right]^2\right\}^{1/2} \quad \text{(Eq 32)}$$

$$\theta_2 = \arctan \frac{I_1(X_1 \cos\theta_1 \mp R_1 \sin\theta_1)}{V_1 - I_1(X_1 \sin\theta_1 \pm R_1 \cos\theta_1)} \quad \text{(Eq 33)}$$

$$I_e = \frac{V_2}{X_m} \tag{Eq 34}$$

$$r_{fe} = \frac{V_2^{\,2}}{\left(\frac{W_n}{m}\right)} \tag{Eq 35}$$

$$g_{fe} = \frac{1}{r_{fe}} \tag{Eq 36}$$

$$I_{fe} = \frac{\left(\frac{W_n}{m}\right)}{V_2} \tag{Eq 37}$$

Calculate

$$I_2 = \left[\left(I_1\cos\theta_1 + I_e\sin\theta_2 \mp I_{fe}\cos\theta_2\right)^2 + \left(I_1\sin\theta_1 - I_e\cos\theta_2 \pm I_{fe}\sin\theta_2\right)^2\right]^{1/2} \tag{Eq 38}$$

NOTES: (1) For induction generator, use alternate (lower) sign in Eqs 32, 33, 38, and 47.
(2) Correct R_1 to the temperature during test.
(3) Cos θ_1 equals power factor during motoring or generating test.

$$X_2 = \frac{V_1 I_1 \sin\theta_1 - I_1^{\,2} X_1 - I_e V_2}{I_2^{\,2}} \tag{Eq 39}$$

$$X = X_1 + X_2 \tag{Eq 40}$$

Repeat Eqs 30 through 40 using the inital ratio of X_1/X_2 from Eq 20 and the new value of X from Eq 40 until stable values for X_1 and X_2 are achieved within 0.1%.

$$X_1 = X \cdot \frac{\left(\frac{X_1}{X_2}\right)}{\left(\frac{1+X_1}{X_2}\right)} \tag{Eq 41}$$

$$X_2 = X - X_1 \tag{Eq 42}$$

$$Z_2 = \frac{V_2}{I_2} \tag{Eq 43}$$

$$R_2 = s \cdot \sqrt{Z_2^{\,2} - X_2^{\,2}} \tag{Eq 44}$$

Then, from the rated voltage no-load test point, calculate

$$X_m = X - X_1 \tag{Eq 45}$$

$$-b_m = \frac{1}{X_m} \quad \text{(Eq 46)}$$

$$V_2 = \left\{\left[V_1 - I_1(X_1 \sin\theta_1 \pm R_1 \cos\theta_1)\right]^2 + \left[I_1(X_1 \cos\theta_1 \mp R_1 \sin\theta_1)\right]^2\right\}^{1/2} \quad \text{(Eq 47)}$$

$$g_{fe} = \frac{W_n}{m \cdot V_2^2} \quad \text{(Eq 48)}$$

The values obtained in Eqs 41, 42, 46, and 48 are used in the equivalent circuit calculations. Rotor resistance, R_2, from Eq 44 and stator resistance, R_1, should be corrected to the specified temperature.

6.7.1.2.3 Locked-Rotor and Load Point Test. The values of X_1, X_2, X_m, and R_{fe} can be determined from the no-load and locked-rotor tests at rated frequency following the procedure in 6.7.1.2.1. The value of R_2 at reduced frequency can be obtained from readings (volts, watts, amperes, slip, stator winding resistance, or stator winding temperature) at a load point using rated voltage or less. The slip must be measured very carefully. R_2 can be obtained by the following procedure after other motor parameters have been determined from the no-load and locked-rotor tests.

For this method, the machine is run uncoupled (or coupled to some reduced load), the voltage is reduced to give approximately full-load slip, and the slip is measured very carefully. After X_1 has been determined from the locked-rotor impedance tests (see 6.7.1.2), the value of R_2 is obtained as follows:

(1) Calculate V_2 using Eq 32.
(2) Calculate θ_2 using Eq 33.
(3) Calculate I_{fe} and I_e using Eq 34 and Eq 37.
(4) Calculate I_2 using Eq 38.
(5) Calculate rotor impedance, Z_2, using Eq 43.
(6) Calculate

$$\frac{R_2}{s} = \sqrt{Z_2^{\,2} - X_2^{\,2}}$$

(7) Obtain R_2 by the multiplication of R_2/s by the measured value of slip in per unit of synchronous speed. Correct R_2 to the specified temperature.

6.7.1.3 Stray-Load Loss (Direct Method)

6.7.1.3.1 Test Method F. See 5.4.2 or 5.4.3.

6.7.1.3.2 Test Method F1. See 5.4.4.

6.7.2 Calculation Form. Form F-F1 (see 10.5) is used to determine the value of total reactance and rotor resistance (except if the alternative test in 6.7.1.2.3 is performed) based on the values of voltage, current, and input power obtained from the no-load and locked-rotor impedance tests. It is arranged on the basis of X_1 and X_2 remaining constant throughout the range of operation of the machine. Should the curve of locked-rotor current vs. voltage depart from a straight line in the range of currents under consideration, each column of calculations in 10.5 should use values of reactance obtained from this curve for the value of I_1 calculated in the column.